Antenna Measurements:
Radiated Emissions/Immunity
NASA/Orion Mars/Moon Capsule

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Overview

• Space Exploration (NASA New Role/Mission)
  – International Space Station (ISS)
    • Space HQ
      – (Old) Space Shuttle (Glider)
      – (New) Space Ship “Orion” ~ Capsule (Crew Module / Service Module)
        • Blunt Body / Parachute Reentry
  – EMI Compliance Tests
    • NASA/JSC Anechoic Chamber Tests (1m) Un-Shielded Components
      – Radiated Emissions/Immunity (MIL-STD)
    • Army/YGP Hanger Tests
      – Near-Field Tests (NF->1m) Build-Up Shielded Parts
        • Sled
        • DART
      – Far-Field Tests (FF->1m) Full System Integration
        • Capsule
Outline

• Introduction
  – Space Exploration [NASA (New) Role/Mission]
    • (New) Space Ship ~ “Orion” Capsule (Space Ship)
    • (Old) Space Shuttle Replacement (Glider)

• Orion Parachute Reentry ~ High-Altitude A/C Drop Tests
  – EMI Tests
    • SoF (A/C Extraction ~ Orion Prototype)
    • RE/RI (RS/RV) ~ MIL-STDs
      – NASA/JSC-Houston(SAC)
        • (1) Components/(1m) (Un-Shielded )
      – Army/YPG-Yuma(Hanger)
        • (2) Parts Build-Up (Shielded Components/NF->1m) Sled/DART
        • (3) Full System Integration ~ Test Vehicle (Shielded Parts/FF->1m) Capsule (CM/SM)
  – EMC Results

• Conclusions
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• Conclusions
Intro: Space Exploration

- NASA
  - US Space Exploration
  - Sites
    - JPL ~ Unmanned Missions (Pasadena, CA)
    - JSC ~ Manned Missions (Houston, TX)
    - KSC ~ Launch Site (Cape Canaveral, FL)
Intro: NASA/JPL

- Unmanned Robotic Planetary Exploration
  - Fly-By/Probes (Inner/Outer Planets)
  - Landers/Rovers (Mars)
    - Deep Space Network
Intro: NASA/JSC

• Manned Missions
  – Moon/Mars ~ Asteroids
    • Lunar Habitat
      – Live in Space
      – Mine Moon’s Minerals
        • Plasma Engine
  • Launch to Mars
Intro: Space Station

- International Space Station (ISS) ~ $150B
  - HQ / Space Operations
    - Research Lab
      - Space Environment
      - Microgravity
    - Observatory
    - Factory
    - Staging Base
      - Moon/Mars
  - Orbit
    - LEO (~370km/7.7km/s)
    - Ionosphere (F Layer)
    - Orbits (15.7/day)
Intro: Past Launch Vehicle (Space Shuttle)

- Space Shuttle
  - (Taxi) Terminated
    - Cost (~1/2$B/Launch=$65K/Kg)
    - Safety/Reliability (~30y)
    - Maintenance
    - Utility (135)
      - Design Limitations (~80%)
        - LEO
        - Equatorial Orbits
        - <22,700 Kg (Payload)
        - Satellite Launch Platform
Intro: Proposed Launch Vehicles

• Short Haul: Earth2LEO(ISS)
  – Russian
    • Proton
    • Soyuz
  – Commercial
    • SpaceX ~ Dragon Supply Ship

• Long Haul: Earth2GEO
  – NASA ---> Moon/Mars(Asteroids)
    • Orion ~ Space Ship
    • Deep Space Exploration
Intro: Proposed Launch Vehicles

- Orion
  - Launch Abort System (LAS)
  - Crew Module (Blunt Body Capsule)
  - Service Module
  - (Adapter)
Space Power Facility: Plumbbrook E³ System Test (Reverberation)

Chamber

Lifting and Positioning Assembly

RF Pallet, including:
- RF Signal Generation
- RF Sensing and Measurement

Safety System

Control and Data Recording
Intro: Crew Module Tests
NASA/JSC & Army/YPG

- Crew Module (Capsule)
  - Designed/Redesigned (Emerging Technologies)
    - Earth Reentry
      - Blunt Body
      - Parachute Decent
  - Parachute Drop Tests (C130/C17)

- Capsule Parachute Assembly System (CPAS)
  - Components
    - Avionic Tray
    - Mid-Air Delivery System Tray
  - Vehicle
    - Sled/Tub
    - DART
    - Capsule (Prototype)
Intro: Blunt Body / Parachute

- Stages
  - Extraction
  - Staggered Chutes
    - Pilot (1)
    - Drogue (2)
    - Mains (3)
  - Pyrotechnic/Explosives
    - Initiators/Cutters
  - Mission Critical
    - EMI/EMC
Intro: CPAS
Capsule Parachute Assembly System

- Parachute Testing
  - NASA/JSC
    - Components (EMI Chamber)
  - Army
    - Build-Up (YPG/Hanger)
    - System Integration (YPG/Hanger)
  - Drop Tests (YPG/Site)
    - Test/Simulation (Final Landing Stages)
      - Experiments (EMI)
        - C130 (Sled/DART)
        - C17 (Capsule)
    - Analysis
      - -20 dB Penalty
Space Environmental Test (SET) Project

Electromagnetic Environmental Effects (E³) System/Component Tests
Outline

• Introduction
  – Space Exploration [NASA (New) Role/Mission]
    • (New) Space Ship ~ “Orion”
    • (Old) Space Shuttle Replacement
  
• Orion Parachute Reentry ~ High-Altitude A/C Drop Tests
  – EMI Tests&Analysis
    • SoF (A/C ~ Orion Prototype)
    • RE/RI (RS/RV) ~ MIL-STDs
      – NASA/JSC-Houston(SAC)
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      – Army/YPG-Yuma(Hanger)
        • (2) Parts Build-Up (Shielded Components/NF->1m)
        • (3) Full System Integration ~ Test Vehicle (Shielded Parts/FF->1m)
  
  – EMC Results

• Conclusions
• Test Types (RE/RS)

• Test Setups
  – Frequency Bands
  – Polarizations
  – Positions

• Modes

• Test Limits

• Testing (Components): Semi-Anechoic Chamber (1m)

• Test Results
## JSC: MIL-STD Tests

### Radiated/Conducted (Emissions/Immunity)

<table>
<thead>
<tr>
<th>EMI Test</th>
<th>Description</th>
<th>EMI Test</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE01</td>
<td>30 Hz – 15 kHz Power Leads</td>
<td>CE03</td>
<td>15 kHz – 50 MHz Power Leads</td>
</tr>
<tr>
<td>CE07</td>
<td>DC Power Leads Spikes Time Domain</td>
<td>CE07</td>
<td>DC Power Leads Spikes Time Domain</td>
</tr>
<tr>
<td>RE02</td>
<td>14 kHz – 10 GHz Electric Field</td>
<td>RE02</td>
<td>14 kHz – 10 GHz Electric Field</td>
</tr>
<tr>
<td>CS01</td>
<td>30 Hz – 50 kHz Power Leads</td>
<td>CS01</td>
<td>30 Hz – 50 kHz Power Leads</td>
</tr>
<tr>
<td>CS02</td>
<td>50 kHz – 50 MHz Power Leads</td>
<td>CS02</td>
<td>50 kHz – 50 MHz Power Leads</td>
</tr>
<tr>
<td>CS06</td>
<td>Spikes Power Leads</td>
<td>CS06</td>
<td>Spikes Power Leads</td>
</tr>
<tr>
<td>RS03</td>
<td>14 kHz – 20 GHz, Electric Field</td>
<td>RS03</td>
<td>14 kHz – 20 GHz, Electric Field</td>
</tr>
</tbody>
</table>

### EMI Test Schedule

**US Segment**

- **CE** Low Frequency: 20 Hz – 10 kHz Power Leads
- **CE RF**: 10 kHz – 100 MHz Power Leads
- **RE**: 10 kHz – 1 GHz Electric Field
- **CS** Low Frequency: 20 Hz – 10 kHz Power Leads
- **CS RF**: 10 kHz – 100 MHz Power Leads
- **RS**: 14 kHz – 20 GHz, Electric Field

**Russian Segment**

- **IEEE/EMC-Brazil PoliUSP 120426**
JSC: RE02/ISS

- 14 kHz – 15.5 GHz
Test Date: 05/24/2010 Test Time: 7:28 pm - 7:50 pm
Sec: 11.4 Steps 8-9 (RE02) Ambient Data (Met the requir.)

EUT NAME: RONAIAT 2 (EUT POSITION SERVO)
TEST CLASSIFICATION: Certification
TF.NO: TPS.NO: EVS-T-EDM-0099 WL1021037
TEST SITE: JSC 814A Rm. 1000
OPERATOR: Cynthia Highower, Charles Brooks
TEST SPECIFICATION: Radiation Emissions Space Station Spec. SSP57000
Frequency Range 14 kHz - 10 GHz 13.5 - 15.5 GHz
120Vac 10 amps fused ~ 5.9 amps meas

SCAN TABLE: "SSP30237 RE02"
Short Description: SSP30237 RE02

<table>
<thead>
<tr>
<th>Start Frequency</th>
<th>Stop Frequency</th>
<th>Width</th>
<th>Meas.</th>
<th>IF</th>
<th>Transducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.0 kHz</td>
<td>14.0 kHz</td>
<td>50.0 kHz</td>
<td>MaxPeak</td>
<td>10.0 ms</td>
<td>200 Hz SAS-200/550-1 686</td>
</tr>
<tr>
<td>50.0 kHz</td>
<td>50.0 kHz</td>
<td>250.0 kHz</td>
<td>MaxPeak</td>
<td>10.0 ms</td>
<td>1 kHz SAS-200/550-1 686</td>
</tr>
<tr>
<td>250.0 kHz</td>
<td>250.0 kHz</td>
<td>30.0 MHz</td>
<td>MaxPeak</td>
<td>5.0 ms</td>
<td>10 kHz SAS-200/550-1 686</td>
</tr>
<tr>
<td>30.0 MHz</td>
<td>30.0 MHz</td>
<td>200.0 MHz</td>
<td>MaxPeak</td>
<td>5.0 ms</td>
<td>100 kHz 3104C 4708 4714</td>
</tr>
<tr>
<td>200.0 MHz</td>
<td>200.0 MHz</td>
<td>1.0 GHz</td>
<td>MaxPeak</td>
<td>5.0 ms</td>
<td>100 kHz 93490-1 1109 1110</td>
</tr>
<tr>
<td>1.0 GHz</td>
<td>1.0 GHz</td>
<td>50.0 kHz</td>
<td>MaxPeak</td>
<td>5.0 ms</td>
<td>1 MHz 3115 S/N 6059</td>
</tr>
<tr>
<td>13.5 GHz</td>
<td>13.5 GHz</td>
<td>5.0 MHz</td>
<td>MaxPeak</td>
<td>5.0 ms</td>
<td>10 MHz 3115 S/N 6059</td>
</tr>
</tbody>
</table>

Level [dBuV/m]

0 20 40 60 80 100

14k 40k 100k 300k 1M 2M 4M 10M 30M 100M 300M 1G 2G 4G 15.5G

IEEE/EMC-Brazil PoliUSP 120426
(1) JSC: RE02 Setup (ISS) ~ Bands
(1) JSC: RE02 Setup (ISS) ~ Positions

TEST SETUP BOUNDARY

\[ N = \frac{X}{3} \text{ (in meters)} \]

Rounded Up to an Integer

EXAMPLE: \( X = 4 \text{ m} \rightarrow N = 2 \)
(1) JSC: RE102 Limit (SS)
(1) JSC: CPAS/PCDTV RE102 (SS) Test Setup
(1) JSC: RE102:CPAS/MDS
Test Setup
Test Bands

- 2-30 MHz (VP)
- 30-200 MHz (HP/VP)
- 200-1000 MHz (HP/VP)
- 1-18 GHz (HP/VP)
(1) JSC: CPAS Test/Analysis

- **Equipment**
  - PCDTV Tray (Unshielded)
  - MDS Tray (Unshielded)
  - Instrumentation Tray (Unshielded)
  - A/C Tray (Unshielded)
  - Video Tray (Unshielded)
  - Cameras (Unshielded)

- **Measurements**
  - RE02
(1) JSC: CPAS RE102 (SS) (2–30 MHz)
(1) JSC: CPAS RE102 (SS) (30-200 MHz)
(1) JSC: CPAS RE102 (SS) (200-1000 MHz)
(1) JSC: CPAS RE102 (SS) (1-18 GHz)
(1) JSC: RE102 Limit (SS) w/o Shielding
(1) JSC: RE102 Limit (SS) w/o Shielding
(1) JSC: Shielding
(1) JSC: CPAS RE102 (SS) (30-200 MHz)
(1) JSC: CPAS RE102 (SS) (200-1000 MHz)
(1) JSC: CPAS RE102 (SS) (1-18 GHz)
(1) JSC: CPAS Shielding Interconnections
(1) JSC: CPAS Shielding Remote Control Wires
TEST DATE: 05/19/2011  TEST TIME: 2:30 pm - 4:44 pm
The Orion Capsule Parachute Assembly System (CPAS)

TEST CLASSIFICATION: Safety of Flight  Battery Operated
TF.NO:  W.O.NO:  EVS-11-EMC-007p  EMCEO-11-011
TEST SITE:  SRC B14  Room 1000  Cynthia Nightower
OPERATOR:  TEST SPECIFICATION:  Radiated Emission MIL-STD-461E Freq. Range 2 MHz - 1GHz
Graph Colors:  1. Black 2-3MHz  2. Blue 30-200MHz H/P  3. Red 30-200MHz V/F
Graph Colors:  4. Grey 200-1GHz H/P p1  5. Green 200-1GHz V/F p1
Graph Colors:  6. Lt Blue 200-1GHz H/P p2  7. Violet 200-1GHz V/F p2

SCAN TABLE: "MIL-STD-461E RE102"
Start Stop Step Detector Meas. IF Transducer
Frequency Frequency Width
10.0 kHz 150.0 kHz 500.0 Hz MaxPeak 15.0 ms 1 kHz SAS-200/550-1 686
150.0 kHz 30.0 MHz 5.0 kHz MaxPeak 15.0 ms 10 kHz SAS-200/550-1 686
30.0 MHz 200.0 MHz 50.0 kHz MaxPeak 15.0 ms 100 kHz 3104C 4708 4714
200.0 MHz 1.0 GHz 50.0 kHz MaxPeak 15.0 ms 100 kHz 3106 S/N 2824
1.0 GHz 16.0 GHz 500.0 kHz MaxPeak 15.0 ms 1 MHz 3115 S/N 6059

Level [dBuV/m]

IEEE/EMC-Brazil PoliUSP 120426
TEST DATE: 06/3-4/2011 CPAS Completely Foiled

The Orion Capsule Parachute Assembly System (CPAS)

TEST CLASSIFICATION: Safety of Flight Battery Operated
TR.NO: W.O.NO: EV5-11-EMC-007P EMCEO-11-011
TEST SITE: JSC BL4 Rm. 1000
OPERATOR: Cynthia Nightower

TEST SPECIFICATION: Radiated Emission MIL-STD-461E Freq. Range 2 MHz - 1GHz
Graph Colors: 1. Black 0-20MHz 2. Blue 20-200MHz H/P 3. Red 30-200MHz V/P
Graph Colors: 4. Grey 200-1GHz H/P p1 5. Green 200-1GHz V/P p1
Graph Colors: 6. Lt Blue 200-1GHz H/P p2 7. Violet 200-1GHz V/P p2

SCAN TABLE: "MIL-STD-461E RE102"

<table>
<thead>
<tr>
<th>Start</th>
<th>Stop</th>
<th>Step</th>
<th>Detector</th>
<th>Measure</th>
<th>IF Transducer</th>
</tr>
</thead>
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<td>50.0 kHz</td>
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<td>100 kHz</td>
</tr>
<tr>
<td>1.0 GHz</td>
<td>18.0 GHz</td>
<td>500.0 kHz</td>
<td>MaxPeak</td>
<td>15.0 ms</td>
<td>1 MHz</td>
</tr>
</tbody>
</table>

Level [dBuV/m]

![Graph of Level vs Frequency]

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(1) JSC: RE102 Limit (SS) w/ Shielding
(1) JSC: RE102 Limit (SS) w/o Shielding
(1) JSC: RE102 Limit (SS) w/ Shielding
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• Introduction
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– EMC Results

• Conclusions
(2) YPG/DART: CPAS Sled/Tub Tests
(2) YPG/DART: DART Tube
(2) YPG/DART: Avionics Tray
(2) YPG/DART: Avionics Tray
Metal/Fabric/Mesh Shield
(2) YPG/DART: DART Integration
(2) YPG/DART: Parts Build-Up
• Unshielded/Shielded Component Tests
  – Apertures (Excitations)
  – B-Dot Probe
  – Spectrum Analyzer

• Analysis
  – Antenna Factor
    • Power ~ Voltage/Current (50 Ohms)
    • Electric Field
      – Magnetic Loop Antenna (Electrically Small)
        • Aperture (Uniform)
        • Waveguide ~ Dominant Mode (TE10/TE11)
    • Extrapolate (NF->1m)
      – Near Field
      – Far Field
(2) YPG/DART: DART Test/Analysis

- **Equipment**
  - PCDTV Tray (Shielded)
  - MDS Tray (Unshielded/Shielded)
  - Instrumentation Tray (Unshielded/Shielded)
  - A/C Tray
  - Video Tray (Unshielded/Shielded)
  - Cameras (Unshielded)

- **Measurements**
  - Discrete Spectrum
  - SNR
    - Ambient Background Noise Floor
    - Reference Level
(2) YPG/DART: CPAS/PCDTV B-Dot Probe ~ Aperture Shielded

DART#E1S: (5/8” OD) Circular-Hole/Shielded

Aperture
Uniform/ Aperture-Rectangular/Ground-Plane
Uniform/ Aperture-Cylindrical/Ground-Plane
aperture (x₀, y₀) = 0.55478" x 0.55478"
shield = 0 (mils)
fringing = 0 (%)
marginal (analysis) = 20 (dB)

E-Field (dBuV/m) ~ RE102/Limit

Frequency (MHz)

RE102-Limit
Mode#1: Direct ~ Aperture
Mode#2: Indirect ~ WG
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV
[2011/11/8(13:58:56)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture(x₀,y₀) = 1.3293"x1.3293"
signal = 0(mils)
fringing = 0(%) 
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV
[2011/11/8(14:18:24)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture(xo,yo) =4.6527"x4.6527"
shield =0(mils)
fringing =0(\%)
margin(analysis)=20(dB)
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV
[2011/11/8(16:26:11)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture(x₀,y₀) = 12"x3"
shield = 0(mils)
fringing = 0(%) 
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV [2011/11/8(16:43:29)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture(xo,yo) = 18"x12"
shield = 0(mils)
fringing = 0(%)
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

DART#E6S:(1-1/2"x2")Cable-Coupler/Shielded

- CPAS/PCDTV [2011/11/8(18:13:22)]
- Aperture
- Uniform/Aperture-Rectangular/Ground-Plane
- Uniform/Aperture-Cylindrical/Ground-Plane
- aperture(xo,yo) = 2"x1.5"
- shield = 0(mils)
- fringing = 0(%) 
- margin(analysis) = 20(dB)

E-Field(dB) vs. RE102/Limit

Frequency(MHz)

RE102-Limit
Mode#1: Direct~Aperture
Mode#2: Indirect~WG
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV
[2011/11/8(18:28:15)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture(x₀,y₀) = 10.5" x 5.75"
shield = 0 (mils)
fringing = 0 (%)
margin (analysis) = 20 (dB)

E-Field (dB) vs. Frequency (MHz)

- Mode #1: Direct ~ Aperture
- Mode #2: Indirect ~ WG
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV
[2011/11/8(18:57:59)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture(x₀,y₀) = 11.75"x3"
shield = 0(mils)
fringing = 0(%) 
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/PCDTV

B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV
[2011/11/8(19:30:47)]
Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane

aperture(xo,yo) = 2" x 1.5"
shield = 0(mils)
fringing = 0(%) 
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

DART#E10S: (1-1/2" x 2") Cable-Coupler/Shielded

E-Field (dB) ~ RE102/Limit

Frequency (MHz)

- RE102-Limit
- Mode#1: Direct ~ Aperture
- Mode#2: Indirect ~ WG

Aperture
Uniform/Aperture-Rectangular/Ground-Plane
Uniform/Aperture-Cylindrical/Ground-Plane
aperture (x₀, y₀) = 2" x 1.5"
shield = 0 (mils)
fringing = 0 (%)
margin (analysis) = 20 (dB)
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded

CPAS/PCDTV/Shielded-YPG19JUL11[2011/11/8(20:8:9)]
DART#E11S:(2-1/4"x5-1/4")SemiCircular-2Holes/Shielded

- Uniform/Aperture-Rectangular/Ground-Plane
- Uniform/Aperture-Cylindrical/Ground-Plane
- aperture \((x_0,y_0) = 4.6527" \times 4.6527"
- shield = 0(mils)
- fringing = 0(%)
- margin (analysis) = 20(dB)

E-Field\((dB)_{\mu m/m}\) ~ RE102/Limit

Frequency(MHz)

- RE102-Limit
- Mode#1: Direct~Aperture
- Mode#2: Indirect~WG
(2) YPG/DART: CPAS/PCDTV
B-Dot Probe ~ Aperture Shielded
### “Starboard” Side Apertures

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>RE102 Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>DART E1S</td>
<td>(5/8&quot;OD)Circular-Hole/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E2S</td>
<td>(1-1/2&quot;OD)Circular-Hole/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E3S</td>
<td>(2-1/4&quot;x5-1/4&quot;)SemiCircular-2Holes/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E4S</td>
<td>(12&quot;x3&quot;)Hatch-Cover/Shielded</td>
<td>Pass/Fail</td>
</tr>
<tr>
<td>DART E5S</td>
<td>(18&quot;x12&quot;)Hatch-Cover/Shielded</td>
<td>Fail/Fail</td>
</tr>
<tr>
<td>DART E6S</td>
<td>(1-1/2&quot;x2&quot;)Cable-Coupler/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E7S</td>
<td>(10-1/2&quot;x5-3/4&quot;)Hatch-Cover/Shielded</td>
<td>Fail/Fail</td>
</tr>
<tr>
<td>DART E8S</td>
<td>(11-3/4&quot;x3&quot;)Hatch-Cover/Pin-Rack/Shielded</td>
<td>Fail/Fail</td>
</tr>
<tr>
<td>DART E9S</td>
<td>(1-1/2&quot;x2&quot;)Cable-Coupler/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E10S</td>
<td>(1-1/2&quot;x2&quot;)Cable-Coupler/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E11S</td>
<td>(2-1/4&quot;x5-1/4&quot;)SemiCircular-2Holes/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART E12S</td>
<td>(1-1/2&quot;OD)Circular-Hole/Shielded</td>
<td>Pass/Pass</td>
</tr>
</tbody>
</table>

### “Port” Side Apertures

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>RE102 Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>DART W1S</td>
<td>(1-1/2&quot;OD)Circular-Hole/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART W2S</td>
<td>(2-1/4&quot;x5-1/4&quot;)SemiCircular-2Holes/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART W3S</td>
<td>(10&quot;x10&quot;)Hatch-Cover/Shielded</td>
<td>Fail/Fail</td>
</tr>
<tr>
<td>DART W4S</td>
<td>(12&quot;x3&quot;)Hatch-Cover/Pin-Rack/Shielded</td>
<td>Pass/Fail</td>
</tr>
<tr>
<td>DART W5S</td>
<td>(3&quot;OD)Circular-Hole/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART W6S</td>
<td>(2-1/4&quot;x5-1/4&quot;)SemiCircular-2Holes/Shielded</td>
<td>Pass/Pass</td>
</tr>
<tr>
<td>DART W7S</td>
<td>(1-1/2&quot;OD)Circular-Hole/Shielded</td>
<td>Pass/Pass</td>
</tr>
</tbody>
</table>
(2) YPG/DART: CPAS/Video Cameras
B-Dot Probe ~ Aperture Shielded

CPAS/Video: YPG19JUL11[2011/12/20(14:21:36)]
DART#C1E:(1200/Outer-Circle)High-Speed/Camera(Unshielded)

- RE102-Limit
- Mode:Direct~Aperture(Pass/Fail)

CPAS/Video
[2011/12/20(14:21:36)]
Uniform/Aperture-Rectangular/Ground-Plane
Aperture\((x_0,y_0) = 6''\times6''\)
Standoff \(= 1.8415\,\text{mm}\)
Fringing \(= 0\,\%\)
Margin(Analysis)\(= 20\,\text{dB}\)
(2) YPG/DART: CPAS/Video Cameras
B-Dot Probe ~ Aperture Shielded

CPAS/Video: YPG19JUL11[2011/12/20(14:47:1)]
DART#:C2E:(1000/Inner-Circle)High-Speed/Camera(Unshielded)

CPAS/Video
[2011/12/20(14:47:1)]
Uniform/Aperture-Rectangular/Ground-Plane
Aperture(x₀,y₀) = 6"x6"
Standoff = 1.8415(mm)
Fringing = 0(\%)
Margin(Analysis)=20(dB)
(2) YPG/DART: CPAS/Video Cameras
B-Dot Probe ~ Aperture Shielded

CPAS/Video: YPG19JUL11 [2011/12/20 (15:49:2)]
DART#C3E: (1100/Inner-Circle) High-Speed/Camera (Unshielded)

- CPAS/Video
- [2011/12/20 (15:49:2)]
- Uniform/Aperture-Rectangular/Ground-Plane
- Aperture (x₀, y₀) = 6" x 6"
- Standoff = 1.8415 (mm)
- Fringing = 0 (%)
- Margin (Analysis) = 20 (dB)

E-Field (dBμV/m) ~ RE102/Limit

- RE102-Limit
- Mode: Direct ~ Aperture (Pass/Fail)
(2) YPG/DART: CPAS/Video Cameras B-Dot Probe ~ Aperture Shielded

CPAS/Video: YPG19JUL11 [2011/12/20 (15:59:7)]
DART#C4E: (0100/Inner-Circle) Low-Speed/Camera (Unshielded)

- **RE102-Limit**
- **Mode: Direct ~ Aperture (Pass/Fail)**

**CPAS/Video**
[2011/12/20 (15:59:7)]
Uniform/Aperture-Rectangular/Ground-Plane
Aperture \((x_0, y_0) = 6'' \times 6''\)
Standoff \(= 1.8415 \text{ (mm)}\)
Fringing \(= 0 \%\)
Margin (Analysis) \(= 20 \text{ (dB)}\)

**E-Field (dB)** \(\sim\) **RE102/Limit**

**Frequency (MHz)**
(2) YPG/DART: CPAS/Video Cameras
B-Dot Probe ~ Aperture Shielded

CPAS/Video: YPG19JUL11 [2011/12/20(16:16:23)]
DART#C5E: (0500/Inner-Circle) Low-Speed/Camera (Unshielded)

- RE102-Limit
- Mode: Direct ~ Aperture (Pass/Fail)

Uniform/Aperture-Rectangular/Ground-Plane
Aperture \((x_o, y_o) = 6" \times 6"
Standoff \(= 1.8415\) (mm)
Fringing \(= 0\) (%)
Margin (Analysis) \(= 20\) (dB)

E-Field (dB) \(\sim RE102/Limit\)
Frequency (MHz)
(2) YPG/DART: CPAS/Video Cameras
B-Dot Probe ~ Aperture Shielded
### Video-Cameras AFT/“North” Side Apertures

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>RE102 Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>DART C1E</td>
<td>(6”x6”)(1200/Outer-Ring)High-Speed (Unshielded)</td>
<td>Fail</td>
</tr>
<tr>
<td>DART C2E</td>
<td>(6”x6”)(1000/Inner-Ring)High-Speed (Unshielded)</td>
<td>Fail</td>
</tr>
<tr>
<td>DART C3E</td>
<td>(6”x6”)(1100/Inner-Ring)High-Speed (Unshielded)</td>
<td>Fail</td>
</tr>
<tr>
<td>DART C4E</td>
<td>(6”x6”)(0100/Inner-Ring)Low-Speed (Unshielded)</td>
<td>Fail</td>
</tr>
<tr>
<td>DART C5E</td>
<td>(6”x6”)(0500/Inner-Ring)Low-Speed (Unshielded)</td>
<td>Fail</td>
</tr>
<tr>
<td>DART C6E</td>
<td>(6”x6”)(0900/Inner-Ring)Low-Speed (Unshielded)</td>
<td>Fail</td>
</tr>
</tbody>
</table>
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded
(2) YPG/DART: CPAS/MDS

Aperture ~ Primary/Unshielded

CPAS/MDS: YPG25JUL11 [2011/12/19(15:20:40)]
DART#P2E: Primary-Tray~Initiator-Pins(Unshielded)

- RE102-Limit
- Mode#1: Direct~Aperture

CPAS/MDS [2011/12/19(15:20:40)]

Uniform/Aperture-Rectangular/Ground-Plane

- aperture(xo,yo) = 5" x 2"
- standoff = 1.8415 (mm)
- fringing = 0 (%)
- margin(analysis) = 20 (dB)

E-Field(dB)\_uv/\_m vs Frequency(MHz)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

DART#P3E:Primary-Tray~Ethernet/1st-Motion/Battery-Charger(Unshielded)

- RE102-Limit
- Mode#1: Direct~Aperture

Uniform/Aperture-Rectangular/Ground-Plane
aperture(\(x_0, y_0\)) = 13.25" x 6.412"
standoff = 1.8415(mm)
fringing = 0(\%)
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

DART#P5E: Primary-Tray~IST(Unshielded)

CPAS/MDS
[2011/12/19(16:23:31)]
Uniform/Aperture-Rectangular/Ground-Plane
aperture \((x_o,y_o) = 4.44\times 4.255''\)
standoff \(= 1.8415\) (mm)
fringing \(= 0\) (\%)
margin (analysis) = 20 (dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG25JUL11 [2011/12/19(16:31:52)]
DART#P6E: Primary-Tray~Switch-Box(Unshielded)

CPAS/MDS
[2011/12/19(16:31:52)]
Uniform/Aperture-Rectangular/Ground-Plane
aperture (x0,y0) = 7" x 3"
standoff = 1.8415(mm)
fringing = 0(%) 
margin (analysis) = 20(dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

DART#P7E: Primary-Tray~CRIO(Unshielded)

Uniform/Aperture-Rectangular/Ground-Plane
aperture(xo,yo) = 10.453" x 3.469"
standoff = 1.8415(mm)
fringing = 0(%) 
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11 [2011/12/13 (20:1:20)]
DART#PZ1S: Primary-Tray~Zipper/Front (Shielded)

- RE102-Limit
- Mode#1: Direct~Aperture

CPAS/MDS
[2011/12/13 (20:1:20)]
Uniform/Aperture-Rectangular/Ground-Plane
aperture (x_o, y_o) = 34"x1"
standoff = 8.1915 (mm)
fringing = 10 (%)
margin (analysis) = 20 (dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11 [2011/12/13 (20:23:48)]
DART#PZ2S: Primary-Tray ~ Zipper/Side/Left (Shielded)

CPAS/MDS
[2011/12/13 (20:23:48)]
Uniform/Aperture-Rectangular/Ground-Plane
aperture (x₀, y₀) = 22" x 1"
standoff = 8.1915 (mm)
fringing = 10 (%)
margin (analysis) = 20 (dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11 [2011/12/13 (20:35:29)]
DART#PZ3S: Primary-Tray ~ Zipper/Side/Right (Shielded)

Uniform/Aperture-Rectangular/Ground-Plane
aperture \((x_0, y_0) = 22" \times 1"
standoff \(= 8.1915 \text{ (mm)}
fringing \(= 10\%\)
margin (analysis) = 20 (dB)

E-Field (dB) \( \sim \) RE102/Limit

Frequency (MHz)

IEEE/EMC-Brazil PoliUSP 120426
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11 [2011/12/13(20:52:15)]
DART#PB1S: Primary-Tray~Bead/Front(Shielded)

Uniform/Aperture-Rectangular/Ground-Plane
aperture \((x_0,y_0) = 34" \times 1"
standoff = 8.1915(mm)
fringing = 10(%) 
margin(analysis) = 20(dB)
(2) YPG/DART: CPAS/MDS Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11 [2011/12/13 (21:5:42)]
DART#PB2S: Primary-Tray~Bead/Side/Left (Shielded)

**RE102-Limit**

**Mode#1: Direct~Aperture**

**Uniform/Aperture-Rectangular/Ground-Plane**

aperture \((x_0, y_0) = 22'' \times 1''\)

standoff \(= 8.1915 (\text{mm})\)

fringing \(= 10(\%)\)

margin (analysis) = 20 (dB)

**E-Field (dB) ** ~ RE102/Limit

**Frequency (MHz)**

IEEE/EMC-Brazil PoliUSP 120426
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11[2011/12/13(21:21:42)]
DART#PB3S: Primary-Tray~Bead/Side/Right(Shielded)

- **RE102-Limit**
- **Mode#1: Direct~Aperture**

**CPAS/MDS:**
[2011/12/13(21:21:42)]
Uniform/Aperture-Rectangular/Ground-Plane
aperture (x0,y0) = 22"x1"
standoff = 8.1915 (mm)
fringing = 10 (%) margin (analysis) = 20 (dB)
(2) YPG/DART: CPAS/MDS
Aperture ~ Primary/Unshielded

CPAS/MDS: YPG10AUG11[2011/12/13(21:33:11)]
DART#PB4S:Primary-Tray~Bead/Back(Shielded)

CPAS/MDS
[2011/12/13(21:33:11)]
Uniform/Aperture-Rectangular/Ground-Plane
aperture(xo,yo) = 34"x1"
standoff = 8.1915(mm)
fringing = 10(%) 
margin(analysis)=20(dB)
(2) YPG/DART: YPG Drop Test C130/Extraction
(2) YPG/DART: YPG Drop Test
Chutes/Landing/Recovery
Outline

• Introduction
  – Space Exploration [NASA (New) Role/Mission]
    • (New) Space Ship ~ “Orion”
    • (Old) Space Shuttle Replacement

• Orion Parachute Reentry ~ High-Altitude A/C Drop Tests
  – EMI Tests
    • SoF (A/C ~ Orion Prototype)
    • RE/RI (RS/RV) ~ MIL-STDs
      – NASA/JSC-Houston(SAC)
        • (1) Components/(1m) (Un-Shielded )
      – Army/YPG-Yuma(Hanger)
        • (2) Parts Build-Up (Shielded Components/NF->1m)
        • (3) Full System Integration ~ Test Vehicle (Shielded Parts/FF->1m)

  – EMC Results

• Conclusions
(3) YPG/Capsule: CPAS RE02 (SS) Open Panels
(3) YPG/Capsule: CPAS RE02 (SS) Closed (0 Deg)
(3) YPG/Capsule: CPAS RE02 (SS) Closed (+30 Deg)
(3) YPG/Capsule: CPAS RE02 (SS) Closed (-30 Deg)
(3) YPG/Capsule: CPAS RE02 (SS) Separation Sled
(3) YPG/Capsule: Test/Analysis

• Test
  – Circular Scans
  – Probes/Hybrid

• Analysis
  – Extrapolated (FF->1m)
  – Attenuated
  – Antenna Factor
(2) YPG/DART: DART Test/Analysis

- **Equipment**
  - CPSS
    - Primary
    - Secondary
  - PTV
    - Open Panels (Unshielded)
    - Closed Panels (Shielded)
  - Cameras

- **Measurements**
  - Continuous Spectrum
    - Ambient Background Noise
    - Reference Level
(3) YPG/DART: CPSS Test/Analysis
HP/3m Secondary (30-1000 MHz)

CPAS/CPSS ~ 01/HP:3m/SN
Raw Measured Data

Power (Measured vs Ambient) [dBm]
-70 -65 -60 -55 -50 -45
10 100 1000
Frequency [MHz]

p_sut[dBmW]
p_amb[dBmW]
CPAS/CPSS ~ 01/HP:3m/SN
Converted Measured Data vs 461 RE102 Limit

Electric Field Intensity (dBµV/m)

- *fs_sut*[dBµV/m]
- *fs_amb*[dBµV/m]
- 461 Limit at 1 meter

Frequency (MHz)

10 100 1000
CPAS/CPSS ~ 01/HP:3m/SN
Adjusted Measured Data vs 461 RE102 Limit

Electric Field Intensity (dBµV/m)

- fs_sut_adj[dBµV/m]
- fs_amb_adj[dBµV/m]
- 461 Limit at 1 meter

Frequency (MHz)
(3) YPG/Capsule: CPSS Test/Analysis
HP/3m Secondary (30-1000 MHz)
(3) YPG/Capsule: CPSS Test/Analysis
HP/3m Secondary (30-1000 MHz)
(3) YPG/Capsule: CPSS Test/Analysis
VP/3m Primary (30-1000 MHz)
(3) YPG/Capsule: PTV Test/Analysis
HP/3m 360/Open (30-1000 MHz)

CPAS/PTV ~ 01O/HP:3m/360 (Open Panels)
Extracted Measured Data vs 461 RE102 Limit

EUT Noise, All Other Data is Ambient Noise

Frequency (MHz)

Electric Field Intensity (dBμV/m)

fs_sut_extr[dBμV/m]
461 Limit at 1 meter
(3) YPG/Capsule: PTV Test/Analysis VP/3m 180/Open (30-1000 MHz)

CPAS/PTV ~ 050/VP:3m/180 (Open Panels)
Extracted Measured Data vs 461 RE102 Limit

Electric Field Intensity [dBμV/m]

All Data is Ambient Noise

461 Limit at 1 meter
(3) YPG/Capsule: PTV Test/Analysis
HP/3m 360/Closed (30-1000 MHz)
(3) YPG/Capsule: PTV Test/Analysis VP/3m 180/Closed (30-1000 MHz)
(3) YPG: CPSS/PTV Test/Analysis VP/3m Secondary/Closed (30-1000 MHz)
(3) YPG: CPSS/PTV Test/Analysis
VP/3m Primary/Closed (30-1000 MHz)

CPAS/CPSS&PTV ~ 02/VP:3m/PN (Closed Panels)
Extracted Measured Data vs 461 RE102 Limit

- Electric Field Intensity [dBµV/m]
- Frequency [MHz]

Ambient Noise

- fs_sut_extr[dBµV/m]
- 461 Limit at 1 meter
(3) YPG/Capsule: CPAS C17/Load
• Experiments (EMI)
  – Avionics
    • Position/Velocity/Acceleration
    • Temperature/Pressure/Humidity
    • Loading(Forces/Torques)
  – Delivery System
    • Firing Events
      – Deploy
      – Release
    • Mortars/Cutters
  – Video
    • Cameras
(3) YPG/Capsule: YPG Drop Test C17

- SoF
(3) YPG/Capsule: YPG Drop Test
(3) YPG/Capsule: YPG Drop Test
Recovery/Repair/Refurbish/Reuse
Conclusion

• SoF Confirmed
  – Components
  – Build-Up
  – System

• Tests/Apertures
  – NF->1m Results
  – FF->1m Results

• Successful Drop Test
  – No Anomalies
    • C130/C17
    • CPAS (Shielding)